The Proliferation of PDC-Type Environments in Industry and Universities

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Abstract. JPL's Project Design Center (PDC), opened in 1994, has become a model for other facilities of the same type in the aerospace industry. More recently, PDC-type environments have been adopted by some university aerospace departments as an educational tool. This paper discusses some of these facilities and their possible future direction.

PDC-TYPE ENVIRONMENTS IN INDUSTRY AND GOVERNMENT

Jet Propulsion Laboratory (JPL). The JPL Project Design Center (PDC) was formed in June 1994 to respond the new NASA imperative of "Cheaper, Faster, Better." The fundamental idea behind the PDC was to improve the quality of space mission conceptual studies and proposals, and to reduce their cost through the use of a concurrent engineering process and integrated computed-based tools.

To improve quality, concurrent engineering teams (containing all the disciplines needed to develop a space mission architecture and conceptual design) use the PDC and its tools to develop alternative mission and system designs and their concomitant costs in a more integrated fashion than was previously done. These teams focus on costs and cost risks, i.e., do design-to-cost, so as to meet NASA's new stringent cost constraints for new missions. Previously, costs were estimated after the mission/system was designed, rather than as an integral part of system trades. The efficiency of conceptual studies and proposals increases since the teams have integrated tools, perform their work in real-time concurrent engineering sessions, and benefit from a learning curve.

Currently, two teams "reside" in the JPL PDC. One of these, called Team X, performs conceptual mission studies and technical/cost studies for proposals for space missions; the other team, known as Team I, performs studies and does proposals for JPL instruments, a major component of JPL's business. The tool sets for these teams are different, reflecting the different nature of the proposal requirements, but both teams are *standing teams* doing their work in real-time concurrent engineering sessions. Team X uses Excel-based software called CEM (Concurrent Engineering Methodology), developed joint by JPL and the Aerospace Corporation as the primary tool for spacecraft sizing and design-to-cost.

The source of the benefits of the PDC-type environment and its team process is found in the vast increase in the communications that can take place. The face-to-face real-time sessions dramatically increases the human-to-human interactions needed for creative mission/system design, while the networked computers running integrated software speeds the time from science requirements and objectives to mission design/ trajectory analysis, to spacecraft performance requirements, and finally to a solution within the mission life-cycle cost cap. That the individuals on the teams work together from study to study generates substantial learning, even though the missions may differ greatly in content. Another source of efficiency is that it now makes economic sense to invest in improving tools, standardizing the content of the resulting study reports, and automating their production.

In aiding human-to-human communication, we found that high-quality visualization has a big payoff. So aside from the computer network and a comfortable work setting, the PDC also contains excellent projection capabilities. These visualization capabilities are expected to increase in the future (see last section). Figure 1 shows the layout of the Team X area within the PDC.

The Aerospace Corporation. Aerospace's CDC (Concept Development Center) is very similar to the JPL PDC. Opened in 1999, the CDC has a very similar layout and uses the same software tool, CEM, as the PDC. The CDC has a standing team to perform conceptual mission studies primarily for the Air Force Space and Missiles Command.

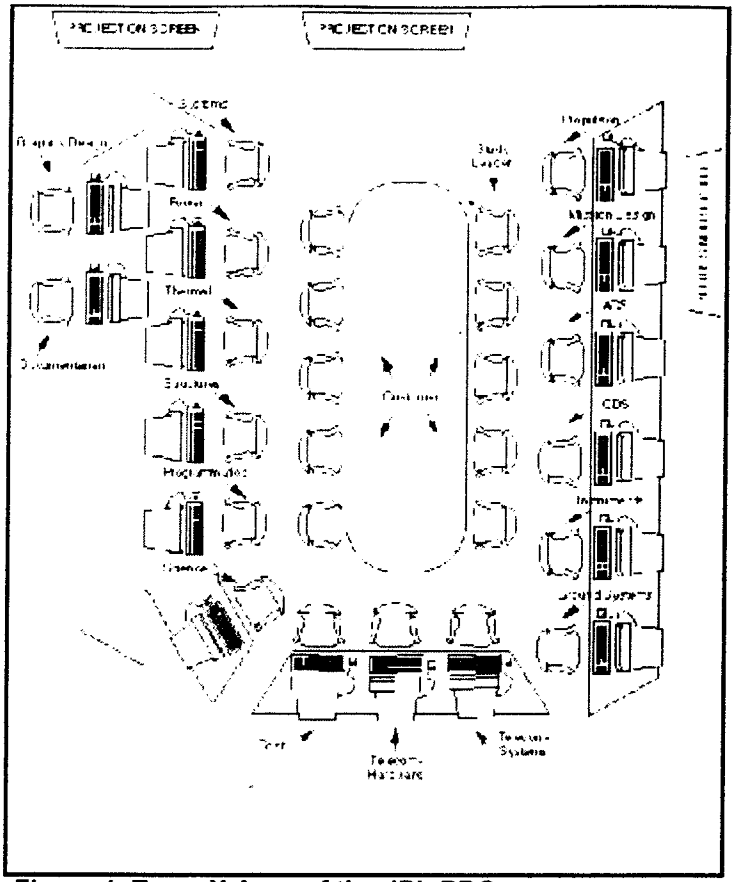

Figure 1. Team X Area of the JPL PDC

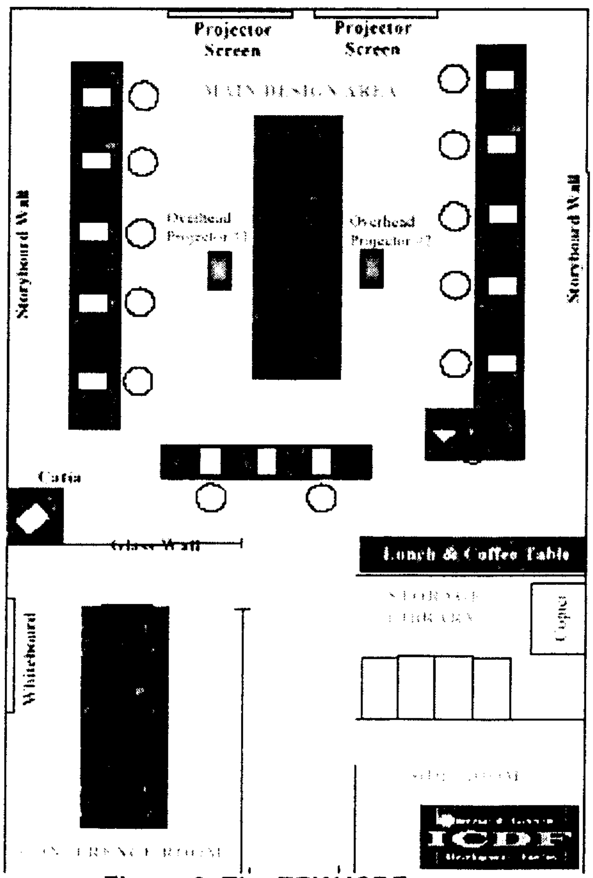

Figure 2. The TRW ICDF

TRW. TRW's Integrated Concept Development Center (ICDF) develops space mission proposals from customer requirements using concurrent design sessions supported by standard component databases and subsystem models. The sessions result in a standard WBS, equipment list, and a CATIA model. The ICDF, opened in 1996, is considered a proprietary part of TRW's business process. Figure 2 shows the layout of the ICDF, which is similar to several industry facilities.

Boeing Military Aircraft Company. Boeing opened its facility, known as "The Center", in December 1999 to support the C-17 program. What makes "The Center" different from the two conceptual design facilities above is that the product, the C-17, was already deployed with the customer and in serial production at Boeing's Long Beach plant. Boeing wanted a better process for determining what product improvement projects made the most sense. The economics of any change would have to be carefully considered, since it might involve changes to the manufacturing flow, operations and support costs, retrofits to aircraft already delivered, and field operation procedures (affecting military effectiveness), in addition to the initial redesign and engineering costs. All of these had to be considered, yet the old process lacked concurrency.

The Center facility is similar to, though smaller than, the JPL PDC. It contains one projector and ten PC workstations around a central table. Each seat has a network port, so that a customer's laptop can be connected. The tool set is still under development because the facility is so new.

Goddard Space Flight Center (GSFC). GSFC's Integrated Mission Design Center (IMDC) opened in July 1997. The facility provides a computer network, workstations, and visualization capabilities. Concurrent design sessions use the IMDC Discipline Engineering Team (DET) of about 14 individuals. Generally the DET develops a baseline concept and identifies potential trades to be performed. Tools include a component catalog, spacecraft catalog, IDEAS, STK, and CAGE. Cost estimates are generally provided based on proprietary parametric models.

The IMDC is moving to a larger facility this summer and may be restructured.

Johnson Space Center (JSC). JSC is developing the HEDS-IDE (Human Exploration and Development of Space-Integrated Design Environment) for conceptual mission studies. The HEDS-IDE, opened in 1997, has no standing teams and has based its software integration on Lockheed-Martin's SBD (Simulation-Based Design) system consisting of Netbuilder software and CORBA. Other tools include the Excel-based HMMM (Human Mars Mission Modeller). Cost estimation has generally not been integrated into the picture, though that remains a goal.

Dornier Satellitensysteme (DSS). DSS's Satellite Design Office (SDO) opened in 1999 to improve the proposals and conceptual studies during pre-proposal and feasibility phases (Phases 0/A). Study teams are generally smaller than Team X, so members must take on more than one role. Study teams are assembled from across the company, with a goal of having at least four individuals able to represent each engineering discipline. The individual selected to represent payload design depends on the type of payload needed for a particular mission. The facility contains 15 Pentium PCs around a central table (similar to the JPL PDC), two projectors, one large screen, and a smart board. Software, known as MuSSat, serves as the primary integrated tool for satellite subsystem sizing and cost analysis. MuSSat was developed as a joint effort of the Technical University of Munich (TUM) and DSS.

PDC-TYPE ENVIRONMENTS AT UNIVERSITIES

California Institute of Technology (Caltech). The Caltech PDC was initiated as a way of teaching integrated concurrent engineering to aerospace students (at both undergraduate and graduate-levels). The now-renamed and enlarged facility, called the Laboratory for Spacecraft and Mission Design, was opened in March 1999, and is modeled after the JPL PDC. It currently contains three Mac and five PC workstations and one projector. The first group of students built mission design software, Excel-based sub-system models for spacecraft sizing, and parametric cost models for each subsystem. These were then linked by a common database to provide an integrated tool. Each year students do a team design project as part of the Spacecraft Systems Engineering course. The course teaches terminology and principles associated with every system and function in a modern spacecraft; approaches for determining the mass, power consumption and other tradable parameters central to space system engineering; techniques for developing reusable models for rapid system design and analysis; and techniques that enhance design team productivity by linking design and analysis tools across disciplines.

Technical University of Munich (TUM). TUM's Division of Astronautics is developing a compact version of the JPL PDC, called the Space System Concept Center (S^2C^2). The goals of this facility is to provide students with hands-on experience in integrated concurrent engineering processes and modeling tools. At this time, approximately ten PC stations are planned, covering the major disciplines of a space mission. The S^2C^2 uses a database-centered design tool called MuSSat (Modellierung und Simulation von Satellitensystemen) that, recall, was jointly developed with Dornier and used in their SDO. Excel-based models are also used. MuSSat's approach is to store and manage data so that the individual engineer the freedom to design as he/she wishes, but structures their work so that every result can be immediately used for system trades. This is very similar to the approach taken by Caltech's PDC.[1] Others at this symposium (if not at this session) are actually doing the work on this facility and can discuss its current architecture and status better than I.

Massachusetts Institute of Technology (M.I.T.). MIT is developing a PDC-type facility within the Department of Aeronautics and Astronautics. Called the DE-ICE (Design Environment for Integrated Concurrent Engineering), the facility's requirements and alternative architectures are currently under study. The DE-ICE will be "used in an academic environment" to support design and analysis, provide guidance to students throughout the design process, and help students define, schedule, and monitor the progress of their work. The facility will be able to operate in several modes: a team design project mode (both real-time and non-real-time); and a lecture/presentation mode. These modes are like that at Caltech. Other supported modes include an intensive design mode and a collaborative mode working with other universities, industry, and government facilities (see final section).

As of this writing, the recommended architecture for the facility emphasizes low life-cycle cost (to the Department). Since each M.I.T. student receives a laptop, the facility will not provide PCs; each user's laptop will be plugged into the system as needed. This removes the initial purchase and upgrade cost for PCs, reducing the capital equipment to be bought and maintained to the servers, monitors, network, and projectors. At this time, approximately 12 to 14 stations and two projectors are planned.

Recommended tools include NASTRAN, CAD, and CFD software, STK, and a set of integrated subsystem models and cost databases.

ENTER ISE

In FY2000, NASA embarked on a multi-year program to revolutionize the way its missions are formulated. The Intelligent Synthesis Environment (ISE) is a high-visibility program "to develop the capability for scientists and engineers to work together in an [immersive] virtual environment, using computational simulations and other tools to model the complete life-cycle of a product/mission before commitments are made to produce physical products." We should see PDC-type environments incorporate some of these capabilities within a year or two.

ISE is NASA-led U.S. national program with participation from (aerospace and non-aerospace) industry, other government agencies, and universities. Some ISE technologies of interest to these stakeholders include the ability to get a heterogeneous collection of computer simulations and models to run together in a (distributed) collaborative engineering environment (smart software); to generate high-quality visualizations for these simulations and models; and to mine data and knowledge bases with intelligent agents.

As part of ISE activities at JPL, an R&D laboratory adjacent to the JPL PDC has already been established to develop advanced simulations and to examine how teams would interact with them through advanced visualization capabilities. This new facility contains four regular projectors along the sides of the facility and one very large, immersive display at the front. The 20' x 6' rear-projection Panoram GVR-120 system is capable of displaying 3 megapixels in 3-D!

In addition to distributive collaborative engineering environments, ISE is also about advanced engineering analyses through simulations that can be rapidly assembled and

[1] Caltech uses ORACLE as a DBMS, while TUM uses 4^{th} Dimension.

federated for a given space mission. To demonstrate their importance, ISE has made advanced cost and risk simulations and tools equal to advanced engineering design and analysis simulations in the program structure.

PDC-type environments will gradually move toward using these advanced simulations even for early conceptual work, if computational speeds continue to advance and costs per computation continue to decline. As virtual presence becomes more of a reality and communications costs decline, I foresee conceptual design for complex missions divided among international teams operating through linked PDCs. The earliest demonstration may be at universities (for example, M.I.T. and TUM), where issues of proprietary data and designs are not so severe.

Lastly, PDC-type environments have been used for conceptual design of missions, not programs. Program architecture also requires multiple disciplines and a variety of tools that must be linked. For example, one must be able to consider the program risk state for changes made to individual missions, and one must be able to determine the effect of individual project schedule changes on program costs and supporting technology developments. PDC-type environments for designing programs is surely another next step.

REFERENCES

The material for this paper came from personal conversations, site visits, briefings, and web sites. Some of the latter include:

pdc.jpl.nasa.gov
imdc.nasa.gov
www.mussat.de/home.php3
www.lrt.mw.tum.de/projekte/1.html

BIOGRAPHY

Robert Shishko is is currently a member of the Engineering Economics and Costing Group of the Jet Propulsion Laboratory (JPL), California Institute of Technology. He has been at JPL since 1983 as a Senior Economist, and is currently working to improve the practice of systems analysis, risk management, and systems engineering at JPL and across NASA.

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